5 STAGES IMPROVEMENT MODEL (5SIM) FOR INTEGRATING LEAN MANUFACTURING AND SIX SIGMA DMAIC

by

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LIST OF ABBREVIATIONS

5SIM	Stages Improvement Model, a business process model developed in this thesis, consisting of a handpicked concoction of tools and techniques from Lean Manufacturing and Six Sigma concepts
CTQ	Critical-to-Quality, the quality characteristics as defined by the customer or stakeholder
DL	Direct Labor, consists of work performed on a product that is a specific contribution to its completion
DOE	Design of Experiment, the complete sequence of steps taken ahead of time to ensure that the appropriate data will be obtained, which will permit an objective analysis and will lead to valid inferences regarding the stated problem.
EHS	Environment, Health and Safety, a department which works directly with the organization's community to prevent accidents, report unsafe conditions, protect the environment, provide training on safety techniques and applicable regulations, and much more.
EMS	Electronic Manufacturing Services, contracting company offering manufacturing and supply chain solutions to electronics and technology companies across a broad range of industries. Scope of service may cover conceptual design, manufacturing, supply chain management and post-manufacturing services.
EOL	End of Line, in electronics industry, is commonly associated with box build processes that are mechanical and assembly centric.
FMEA	Failure Mode and Effects Analysis, a systematized technique which identifies and ranks the potential failure modes of a design or manufacturing process in order to prioritize improvement actions
FOL	Front of Line, in electronics industry, is commonly associated with PCBA (printed circuit board assembly), where components are mounted onto a circuit board.
IPQA	In Process Quality Assurance, a vital part of manufacturing process to ensure that any defects in the process is at a minimum and that any defective product does not reach the customer.
JIT	Just In Time, a manufacturing process that produces products just in time to meet orders, not for stock.
MIT	The Massachusetts Institute of Technology, a research institution and university located in the city of Cambridge, Massachusetts

directly across the Charles River from Boston's Back Bay district.

OEM	Original Equipment Manufacturer, a company which manufactures hardware or software which is modified or re-badged from one or more other products and sold directly to end users.
SOP	Standard Operating Procedure, documents that describe a specific method of accomplishing a task that is to be followed precisely the same way every time.
TR Type 2	Technical Report Type 2, a code for potential standard when the subject is still under technical development, or where for any there reason there is the future possibility of an agreement on an International Standard.
UPH	Units Per Hour, the number of defect-free parts produced per hour worked.
WIP	Work-In-Progress, generally describes inventory that is currently being processed in an operation or inventory that has been processed through one operation and is awaiting another operation. Term also used in financial account that contains the dollar value of all inventory, labor, and overhead that has been issued to production but has not yet produced a finished product.

MODEL PENAMBAHBAIKAN (5SIM) UNTUK MENCANTUMKAN KAEDAH "LEAN MANUFACTURING" DAN ALATAN SOKONGAN "SIX SIGMA"

ABSTRAK

Pada permulaan abad ke dua puluh satu, ekonomi dunia telah menjadi semakin terbuka kepada persaingan berbanding dengan abad-abad yang lalu. Ini didorong oleh permodenan dari segi teknologi, sistem komunikasi, pelonggaran perjanjian perdagangan dan juga sistem pengangkutan. Negara-negara membangun di dunia mengambil kesempatan ini untuk bersaing dengan negara-negara maju dalam semua bidang industri. Malaysia, sebuah negara yang telah menikmati perkembangan industri yang pesat sejak tiga dekad lalu, kini bukan lagi dalam golongan negara yang berkos rendah. Dari beberapa tahun lepas, satu fenomena di mana kerja industri pembuatan and peluang perkerjaan telah menjadi semakin berkurangan dan penutupan kilang-kilang juga telah menjadi perkara biasa di sektor industri tempatan. Berdasarkan situasi ini, penyelidikan ini telah dijalankan sebagai satu langkah untuk mengurangkan kehilangan industri pembuatan dari Malaysia ke negara yang lebih rendah kos pengeluarannya dengan mengemasikinikan operasi untuk meningkatkan tahap persaingan. Penyelidikan ini telah menggunakan cipta satu model proses perniagaan yang dinamakan 5SIM (5 Stages Improvement Model) berdasarkan kaedah Pembuatan Lean dan Enam Sigma. Penyelidikan ini juga merangkumi butir-butir dan objektif setiap peringkat, dan dokumentasi teliti kerja Lean dan Enam Sigma yang telah dilaksanakan sehingga kini. Juga turut disertakan dalam penyelidikan ini adalah dua kajian kes di mana 5SIM digunakan dalam kerja pemajuan proses di kilang di Malaysia. Kesimpulan yang didapati dari kedua-dua kajian kes ini juga

dibandingkan antara satu sama lain dan satu penemuaan penting menunjukkan bahawa walaupun berdasarkan model, suasana, objektif, alatan dan teknik yang sama, kemahiran pasukan memainkan peranan yang penting dalam menentukan bagaimana projek dijalankan, walaupun pada akhirnya kedua-dua kajian kes ini mencapai matlamat yang sama. Pengalaman yang telah dipelajari daripada keuda-dua kajian kes ini juga dibincangkan dengan terperinci untuk dijadikan sebagai ukuran bagi yang lain yang ingin mengambil bahagian dalam bidang Lean Enam Sigma untuk memastikan organisasi mereka mampu bersaing dengan sihat. Kedua-dua kajian kes ini telah membuktikan bahawa model 5SIM berjaya dalam mengendalikan projek permajuan dan untuk langkah seterusnya adalah untuk meluaskan penggunaan 5SIM melampaui batasan pembuatan dan menuju ke sector lain dalam rantai pegeluaran.

5 STAGES IMPROVEMENT MODEL (5SIM) FOR INTEGRATING LEAN MANUFACTURING AND SIX SIGMA DMAIC

ABSTRACT

At the dawning of the twenty first century, the world economy had become more open to competition as it had been for the past centuries. Fueled by advancement of technology, communication and deregulated trade and transportation, low cost countries around the globe had taken the advantage on this access to compete with high cost countries on all fronts of industries. Malaysia, a country which has been enjoying the industrial boom for the past three decades, was no longer a low cost region. For the past few years, it had experienced a steady decline in manufacturing jobs opportunities and facilities close down had been a common sight in the local industrial sector. Based on this scenario, this research was triggered as an effort to curb the attrition of manufacturing businesses out of Malaysia by improving the competitiveness of the Malaysian industry. In doing so, this research applied a business process improvement model (the 5SIM – 5 Stages Improvement Model) based on Lean Manufacturing and Six Sigma tools and techniques. The research covered the details and objectives of each stage of the model, and a comprehensive survey on Lean Six Sigma efforts that had been done to date. Also included in this research was the execution of two case studies based on the 5SIM business process in a manufacturing facility in Malaysia. The case studies results comparison were done to show an interesting finding where based on the same model, business process, environment, objective, tools and techniques, the team's skill set composition would greatly affect the execution of the project, but still achieved the same goal ultimately. The lesson learnt

from these two case studies were also elaborated and discussed extensively to serve as a benchmark and guidelines for others who would like to embark on a Lean Six Sigma journey to keep their organization competitive and healthy. As both case studies had successfully validated the 5SIM model, future work continuation was to expand the 5SIM business process beyond the boundaries and move towards other areas of the supply chain.

CHAPTER 1 INTRODUCTION

1.1 Background

In this era of globalization, keeping a lean operation in order to keep up with the competition was no longer an initiative, but a crucial survival means to ensure a company's continuous existence and subsistence. New methods were being developed everyday and business models constantly being refined, all in the hope to keep cost down and stay ahead in the race. For the past decade, the method that was most commonly regarded as the holy grail of modern day manufacturing was Lean Manufacturing. The origin of Lean concepts was generally accepted to have evolved from the TPS (Toyota Production System) developed by Toyota a few decades ago.

At the same time, Six Sigma, a set of techniques focused on business process improvement and quality measurement originally developed by Motorola back in the 80s and widely accepted as the quality yardstick, were evolving towards the next level. Coined as the Digital Six Sigma that had its root from the control of a process to the point of ± six standard deviations from a centerline, or 3.4 defects per million items, it provided a quality package that enabled businesses to improve the capability of their business processes.

1.2 Problem Statement

The culture of Lean and Six Sigma had been sweeping through the world in the past two decades. With the boundaries of countries and trades increasingly transparent due to advancement in communication technology and globalization, the industries of the world found themselves competing in the same arena in all fronts of manufacturing and business excellence.

Malaysia, which had enjoyed the industrial boom for the past three decades, had to find ways to remain competitive in both cost and quality to remain in the game. The past few years, the local electronics industries had seen manufacturing businesses shifting to lower cost regions such as China and India. In order to curb business attrition from Malaysia, local industries would need to change to improve the efficiency of their operations.

In view of this trend, this thesis explored the development and execution of a business process model based on Lean Manufacturing and Six Sigma that would aid Malaysian industries in improving their operations and remain competitive.

1.3 Objectives

Most of the Lean Manufacturing efforts were closely associated with tool sets and techniques originated from Japan, such as 5S, SMED (single minute exchange of die), Pokayoke, et cetera. In practice, a lot of companies, often at the advice of the consultants, once embarked onto a Lean journey, would discard off other existing tools and techniques, even though these existing tools and techniques had been proven to be useful and beneficial, such as Six Sigma. With that in mind, the objectives of this thesis were to explore how two very distinct tool sets: Six Sigma framework and Lean Manufacturing could be melded together to bring improvement activity approaches to the next level. The objectives for this thesis were set as follows:

1. Understand the Lean Manufacturing and Six Sigma implementation in various companies.
2. Perform environment scan on other improvement models currently being used in the market
3. Develop a continuous improvement business process model of Lean Six Sigma
4. Develop the implementation and proliferation plan

1.4 Scope of Research

The scope of this thesis encompassed two case studies that were working towards the same objective of conversion cost reduction. The methodologies covered were Lean Manufacturing and Six Sigma. The case studies consumed four months each. Data analysis covered a time frame of more than two years, with up to one year four months of projected future data and one year historical data. Also included in the scope were literature reviews focused on Lean and Six Sigma to explore the possibilities of melding both techniques together. 5SIM, a practical working model based on Lean and Six Sigma methodology would also be developed to enable the execution and proliferation of improvement initiatives.

1.5 Challenges

In most cases of the Lean Manufacturing implementation, few implementers had shared about the details and results, and only a handful had provided insights on the bitter sweet experiences throughout the implementation. Most of the time, the published official reports were so polished that only the successful stories were shared, and the rest were kept for internal assessment in the respective companies only.

There were not many reference materials available on how to fuse Lean Manufacturing with Six Sigma. Therefore, the main challenge in this thesis was to physically experience the roadblocks and lessons learnt from an implementer's perspective, document it in a flavor suitable and available for both industry and academic consumption. Millions of dollars had been put at stake to implement Lean Manufacturing in the following two case studies and the eventual full scale implementation, and it was hoped that the exposé would serve as a revelation to the academic realm of what theories worked practically or otherwise. On the other hand, the buyback for the industries was to use these case studies as a reference on their respective Lean Six Sigma implementation, so that costly pitfalls would not be repeated.

1.6 Layout of Thesis

This thesis began with Chapter 1, with the brief introduction of both the Lean Manufacturing and Six Sigma concepts. This was followed by a zoomed in outlook on globalization and its impact on the once thriving electronics industries in Malaysia. In the panic state to improve their operations, these companies generated a demand for improvement techniques packages, and this in turn created a pool of self proclaimed turn-around consultants which at times do more harm than good to the companies they advised. This happened when consultants misled and convinced the companies to execute their half cooked techniques due to the lack of in depth knowledge of the nature of the companies. In responding to these problems, the thesis objective would create a practical business process model to lower or eliminate the chances of improvement initiatives failure by meticulously filter out the details commonly overlooked during the execution stages of Lean Six Sigma methodology.

Chapter 2 drilled into the depths of Lean Manufacturing, the origin and how it had evolved throughout the years. It was followed by the literature surveys and comprehensive discussions of Lean Manufacturing tools such as the Value Stream Mapping, Quick Changeover, One Piece Flow, Kanban systems, Poka Yoke, 5S, Line Optimization, Cellular Manufacturing, Takt time, Fishbone Diagrams and so on. Next, the discussion veered towards Six Sigma, and elaboration on one of the Six Sigma improvement tool: the DMAIC its sub components – Define, Measure, Analyze, Improve, Control. Also, environment scan was performed on the global industry to comprehend and evaluate the improvement models currently being used, such as iCMM (Integrated Capability Maturity Model), ISO/IEC TR 15504, Evolutionary Delivery Process Model, PDCA (Plan Do Check Act), Raytheon Three Phase Process Improvement Model, Raytheon Six Sigma Improvement Model, The IDEAL^{SM}, ADDIE Process Improvement Model, The Continuous Process Improvement Model and so on.

Chapter 3 focused on the business process model 5SIM that was developed based on the Six Sigma DMAIC framework, and detailed explanations were provided for each of the five stages: Define the Objective, Data Collection and Measurement, Analyze the Data Collected, Implementing Improvement Plan (Pilot), Standardization and Repeatability Control.

Chapter 4 was a documentation of the two Pilot case studies executed in accordance to the 5SIM business process model. The detailed results of the Pilot case studies that proved that 5SIM was a working model and demonstrated enough flexibility for execution and proliferation in a wide range of applications.

Chapter 5 covered the discussions and lesson learnt from the two case studies, comparison of results and the reasoning behind them. This Chapter ended with the discussion of future work continuation based on the lessons learnt from this thesis.

CHAPTER 2 LITERATURE SURVEY

2.1 Introduction

The Literature survey of this thesis revolved around Lean Manufacturing principles and Six Sigma. In essence, Lean focused on the removal of waste, which is defined as anything not necessary to produce a product or service, while Six Sigma assumed the outcome of an entire process would be improved by reducing the variation of multiple elements involved in the process.

2.2 The Origin of Lean Manufacturing

Though there had been numerous claims on the real origin of Lean Manufacturing principles, it was generally accepted that the concept of Lean Manufacturing evolved from the TPS, developed by the Toyota Motor Car Company (Togo and Wartman, 1993).

Toyota started with the manufacturing of looms for making cloth, which later branched into the manufacturing of engines, small delivery vehicles and trucks during WWII. As Japan was a country with scarce natural resources, Toyota was conditioned and confined to do more with less, and the motivation for TPS culture were gradually established with the emergence of tools and techniques to increase efficiency and minimizing waste.

Toyota was more of an innovator, in the sense that it leveraged tools from Henry Ford – the assembly line for automobile, from Taylor – the inventor of Modern Management techniques and Industrial Engineering, and from Dr. W. Edwards Deming – the Father of Modern Quality Management (Konz and Johnson, 2000). Based on these early beginnings, the techniques were refined, honed, and improved in all areas.

The North American automobile market by then was still dominated by the Big Three – General Motors, Ford and Chrysler. But with the invasion of the North American automobile market by Volkswagon in the 1960's, and Toyota in the 1970's, and a world-wide recession that came in at the wrong time, the American automotive industry was destabilized and was left with no choice but to take up drastic changes to remain in business (Togo and Wartman, 1993).

In the meantime, North American automotive watchdogs were looking for an explanation on how Toyota could manufacture a car, ship it to North America, and sell it faster and cheaper than domestically made vehicles. Huge import tariffs imposed by North America had failed to stop the influx of these affordable, quality cars (Iacocca and Novak, 1984). Moreover, the design and features of the Japanese vehicles innovated and evolved at an extremely rapid rate compared to their North American competitors, which tended to stick to an old design for a very long time.

In order to answer this question, a five year, $5 million research project was conducted by MIT to analyze the world-wide automotive industry in 14 countries in terms of design, markets, and manufacturing. The result of the research was published in a book "The Machine that Changed the World", where Dr. Womack and his IMVP (International Motor Vehicle Program) group at MIT successfully identified the key differences between Toyota's TPS, European auto industry, and the North America's automobile manufacturing systems (Womack and Jones, 1991). It had been concluded that the North American and European had assumed and accepted the mass production theory and honed it to perfection. However, the Japanese and Toyota had used mass production as a starting point and evolved it to TPS.

TPS, however useful it was, still pose a barrier to gain wide acceptance in the industries as it was still a Toyota system. To encourage the adoption of TPS in the industrial realm, Womack coined the system ‘Lean Manufacturing’ to eliminate the ‘not invented here’ syndrome.

Lean Manufacturing represented a unified, comprehensive set of philosophies, rules, guidelines, tools, and techniques for improving and optimizing operations. Lean had evolved over time. Although Lean application started in high volume repetitive manufacturing environment, most notably in the automotive industry sector, the current Lean principles application had spanned to a larger scope of industries to encompass the service sector, making remarkable impression in health care, travel services, sales, marketing, fast food and so on.

2.3 Major Tools & Techniques of Lean Manufacturing

There was no one definite list of what tools and techniques would roll under Lean Manufacturing. In theory, methods established to eliminate waste and improve operation efficiency could be regarded as tools for Lean Manufacturing. In this regard, Lean was renowned for its focus on reduction of the original Toyota's Seven Wastes, namely defects, overproduction, transportation, waiting, inventory, motion, and over-processing in order to improve overall value to customer and profitability.

A few relevant tools had been short listed for consideration for usage in this research.

2.3.1 Value Stream Mapping

Value stream mapping (VSM), also known as an end-to-end system map, was a tool that was used to systematically draw out the flow as a product or service moved its way from one function to subsequent functions throughout the supply chain. A value stream map took into account not only the activity of the product, but the management and information systems that supported the basic process. By taking a value stream perspective, the big picture was being worked on, not just individual processes, and improving the whole system instead of just optimizing bits and pieces of it.

Work done by Jones et al. (1997) showed that VSM enabled the detailed understanding of the waste or inefficiencies that laid in existing systems, and that the understanding was required so that radical or incremental improvements could then be made in the development of a Lean system.

Work done by Hines and Rich (1997) indicated that there were a few variants of VSM methodologies and the selection on which to use would depend on which what type of waste that needed to be eliminated. Further work by Hines et al. (1998) compared the strength and weakness of these VSMs.

There were seven components that made up VSM: the process activity mapping, the supply chain response matrix or time compression matrix, production variety funnel, quality filter mapping, demand amplification mapping, decision point analysis and physical structure mapping (Hines and Rich, 1997).

Value stream mapping has been widely used in various manufacturing and service industries (Hines and Rich, 1999). An example would be an application in the distribution company, which had, with the help of VSM, developed from a situation where it had only a very limited supplier integration process to a strong system with a well charted future development plan that was self-sustaining without significant outside facilitation support.

2.3.2 Quick Changeover

Quick Changeover was originated from Dr Shigeo Shingo's principles on SMED (Single Minute Exchange of Die) (Shingo, 1991). It was a setup reduction technique aimed at eliminating non value added activities in the tool setup inherent in a majority of manufacturing processes. A successful quick changeover enabled a factory to change from one product to another quickly and efficiently.

The SMED technique worked by dividing the set-up and change-over procedures into external and internal elements. The next step was to concentrate on reducing the internal time taken to maximize the equipment's availability time that was consumed during a change-over. The 'Single' in SMED meant a single-digit number of minutes needed to perform the change over. SMED or quick changeover techniques had been widely used in JIT manufacturing processes, resulting in cycle time reduction in products and services, producing products that were better, cheaper and could be delivered faster. This in turn contributed to an elimination of the need to stock large inventories. Quick Changeover was a critical component of Lean Manufacturing as it reduced scheduled downtime for setup and increased machine availability.

For example, a pharmaceutical manufacturing facility in North America introduced the Quick Changeover technique to its printing department (Nunez, 2006). There was a significant bottleneck in the Printing department, where the name of the medication was printed on the tablets. The company wanted to reduce its set-up time in the Printing department in order to achieve higher output.

The Quick Changeover program was launched by forming a Quick Changeover team. The first task was to develop a current and future state of the process, videoed the existing processes, reviewed the video, identified changeover improvement priorities, established baseline times and goals for time reduction. Then the changeover process (i.e. internal and external activities) was analyzed, worked to reduce changeover time, and established an implementation schedule. Three days after the implementation completion, the company was able to cut the changeover time required from one batch to another from two hours to 17 minutes, representing a 86% reduction in the amount of time needed for changeover from batch to batch. This had helped the company to increase throughput in the Printing area by 57%, allowing them to meet the customer's needs more efficiently.

Similar research done by Gilmore and Smith (1996) of a SMED implementation in a pharmaceutical manufacturer in Europe showed the same benefits gained. Research done by Moxham and Greatbanks (2001) showed that up front work and prerequisites for SMED implementation above could be applied in the textile industries too. Patel et al. (2001) showed that SMED would achieve better results when it was applied in parallel with Poke Yoke, as Poka Yoke eliminated opportunities for mistakes during setup.

2.3.3 One Piece Flow

Research done by Thompson (Thompson: 1967) showed that the traditional non repetitive production systems such as job shops were capable of producing at a high product mix with high WIP (work in progress) inventories, while repetitive production systems such as continuous flow assembly lines were typically efficient, but lack the flexibility to produce a high variety of products.

Conventional manufacturing techniques manufactured goods in large batches simultaneously, or transferring parts that was accumulated in a bin at the same time. This was opposite to the definition of One Piece Flow.

One Piece Flow, or single piece flow, was the ideal state where goods were manufactured one at a time on each process, and flowed through the manufacturing system as a single unit. One Piece Flow worked well in the JIT (Just-in-Time) environment and along Lean Manufacturing implementation. Studies conducted by Rooks (Rooks, 2000) had indicated substantial benefits reaped from One Piece Flow implementation in the aerospace industries.

To implement One Piece Flow, first of all, batch sizes at the production were recorded to serve as a baseline. When a pool of batch size data was accumulated, the next step was to determine the optimum batch size and transfer size.

In One Piece Flow, the batch size goal was to achieve one unit of product in a batch. However, due to practicality, the irregularities inherent in manufacturing need to be taken into account and thus, a minimum safe batch size would be used.

The minimum batch size formula used was: (McGee, 2005)

Min Batch Size = SI/2(1-X-PI) --(1)

Where: S = Setup Time

I = Demand Rate

X = Defect %

P = Processing Time per Unit

With the assumption that all products have the same demand and process parameters.

As the Min Batch Size formula did not account for variation in demand, it needed to be addressed separately. The approach was different for manufacturing sector and service sector.

For manufacturing, the objective was to have additional finished goods inventory built in accordance with the safety stock formula: (McGee, 2005)

Safety Stock = s service level X (LT) to the power b -----------------------------(2)

Where: s service level = desired service level (stock out coverage) = number of standard deviations, relative to the mean, carried as safety stock.

For example:

- Service Level = 1 means that one standard deviation of safety stock is carried, and on average, there will be no stockouts 84% of the time
- Service Level = 2 means that two standard deviations of safety stock is carried, and on average, there will be no stockouts 98% of the time

Lead Time (LT) = Replenishment Lead Time

b = a standard lead time reduction factor (generally set at 0.7)

For the service sector, as it was not possible to stock up, and customers must wait in queue to receive value added services, therefore the queue time formula was used: (McGee, 2005)

Queue Time ~= (Service Time/# of cross-trained servers)/(n/n-1) ------------ (3)

Where: n = approximate % capacity at which servers are operating

However, not all manufacturing system would be able to reap the full benefits from a One Piece Flow implementation. Before jumping into a One Piece Flow implementation, it was wise to analyze the overall manufacturing system and look for symptoms if there was really a need, and not implement for implementation's sake.

The most important was to first look from the customer's perspective, to see if there was a long delivery lead time. One Piece Flow implementation ensured the product would continuously flow and eliminate or reduce the delivery lead time.

The second was to look at the store inventory and determine if there was a high level of obsolete items. One Piece Flow implementation reduced the chances of keeping an item until it obsoletes as work in progress was minimized.

The third was to look at the IPQA (In-Process Quality Assurance) and production data and see if there were symptoms of large batches of defects and rework, all with the same or similar defect. One Piece Flow, by ensuring that the level of WIP was kept to a minimum, minimized the need for rework and scrap when a defect was detected at the downstream of the manufacturing flow.

The fourth was to observe the WIP leftovers at the beginning and at the end of production run. The ideal case of One Piece Flow should be that if a model was continuously running across two shifts, the ideal WIP level should be equal to the number of process or DLs (direct labor) in the line.

If the manufacturing facility was not showing any symptom of weak performance on any of the abovementioned four items, improvement should be focused on other possible contributing factors rather than driving for One Piece Flow.

2.3.4 Kanban (Inventory Control through Card System)

Kanban originated from the Japanese word carrying the meaning “visible record” (Chan, 2001). At present day manufacturing, the term Kanban had been used extensively to represent a family of different production and inventory control systems. Kanban worked on the basis that each process on a production line pulled just the right number and type of components that a process required, at just the right time. It was a signaling tool to trigger what items to manufacture, the time to start manufacturing, the time to stop manufacturing, the quantity to manufacture, and the next process or location to deliver them to once an existing task was completed. The mechanism used was a Kanban card. This was usually a physical card but other devices in electronic formats could be used as well.

The equation for computing the optimal number of Kanbans required for production originated from Toyota, and was generally expressed in the following equation: (Sharafali, 1997)

$$N= [d_{ave}(t_w+t_{pc})(s)]/k \quad \text{---}(4)$$

Where: d_{ave} is the average daily demand

t_w is the waiting time

t_{pc} is the processing time per container

s is the safety factor

k is the container size

Similar method was used by Singh et al. (1990) for optimal Kanban calculations. As Lean Manufacturing was a pull system where demand fluctuated, setting a fixed Kanban number could be hard. Gupta et al. (1999) introduced a new theoretical method of flexible Kanban to overcome this shortcoming, while Takahashi et al. (1997) suggested a queuing network model to improve the Kanban system by modifying the flow of information.

Once a Kanban system was implemented and the system was operating well and stable, Kanban can be used as a simple, powerful tool to drive for on-going continuous improvements in the manufacturing process. This could be done by the removal of one of the Kanban cards, and by doing so would de-stabilize the system, forcing it to self adjust to regain stability through further process improvements. If the improvement cannot be made immediately due to technological limitation or constraints, the Kanban card could be replaced immediately, and the system re-stabilized to its previous stable state. Close supervision must be done throughout the experimental process to ensure no negative impact on production deliverables.

2.3.5 Poka Yoke (Mistake Proofing)

Poka-yoke was a Japanese word carrying the meaning of mistake-proofing, and were commonly associated with processes or devices that were used either to prevent the occurrence of causes that resulted in defects in products (Shingo, 1986). The best Poka Yoke approach was to enable the ability to carry out inspection effortlessly on each item that was produced to determine whether it was defective.

Any mechanism that had the capability to either prevent a mistake from being made or made the mistake obvious at one glance could be considered a Poka Yoke device. The causes of manufacturing defects were induced during production of goods, and defects were ruled as a result of failure to identify those errors. In the event these errors were discovered and eliminated beforehand, defects would be non existent.

A case example of a Poka-Yoke device implementation was a welding operation at GM (General Motors) (Shetty and Buehler, 1987). The welding process involved the welding of nuts on the sheet metal panel. The nuts were automatically fed into the welding machine, and the welding process was out of sight from the machine operator. The welding machine was unable to detect missing nuts and would still weld even when nuts were missing, resulting in major repair or rework activity. A Poka Yoke solution that was put in place in order to eliminate missing nuts, the electrode current flow was routed through the nut. In the event a nut was missing, welding would not take place.

At times, in practice, it was hard to determine the most effective approach to start a Poka Yoke improvement. One of the methodologies aiding these decisions was to identify the sensory alert regulatory function in order of preference: Control, Shutdown, Warning, and Sensory alert (Beauregard et al., 1997). Control methods eliminated the opportunity for errors to occur. This was the most preferred method but sometimes failed to achieve the acceptable level of return on investment. On the other hand, work done by Patel et al. (2001) indicated that simple fail safe such as fouling pins and offset holes would proved to be cost effective and fulfilled the Control method requirements. The second preferred method was the Shutdown, where equipment or process was stopped when an error occurred. Though the error could be detected, the defective product or WIP had been produced at this point, and a rework or scrap cost was unavoidable. The third was the Warning method, where active visual or audio signals were used to notify the operators or users that an error had occurred. Compared to the Shutdown method, this would incur more rework or scrap as defective units continued to be produced until the operator shut the equipment down. The least preferred was the Sensory method, where errors were made to appear in a very obvious manner, but was totally dependent on the operator or user to actually perform the check.

Poka Yoke was not a generic solution for all issues (Grout, 1997). It worked well in manual operations where worker vigilance was needed. In terms of equipment, it was most beneficial where adjustments and readjustments were constantly required. In a process, it would help most in areas where statistical process control was difficult to apply or ineffective, and when data collection from tools were based on attributes and not measurements. It would be able to cushion the severity and occurrence frequency of errors in tasks where training cost and employee turnover were high.

2.3.6 5S (Sort, Set in order, Shine, Standardize, Sustain)

Research by Ahlstrom (Ahlstrom, 1998) argued that the elimination of waste was the most distinguished principle in Lean Manufacturing.

5S was a tool used to reduce waste and optimize productivity through maintaining an orderly workplace, usually with supplementary visual signs to achieve more consistent operational results. 5S was scheduled as the first activity in a Lean Manufacturing implementation as by driving the factory towards a cleaner environment and orderly workplace, adaptation of other Lean tools would be much easier. Furthermore, 5S implementation commonly did not involve any expensive purchases and therefore would be a good starting point to get management buy-off.

The 5S originated from the Japanese words: Seiri, Seiton, Seiso, Seiketsu and Shituske (Hirano, 1995). There had been a few English versions of the words the 5S stood for. For example, some version was Separate, Set in order, Shine, Systemize and Sustain, while another version was Sort, Straighten, Shine, Standardize and Sustain. Regardless of which versions they all carried the same message.

In the fist Sort step, each personnel was required to examine their own workstation, segregate the garbage or items that would no longer be needed from the useful ones. The rubbish were thrown away or scrapped while the excessive items were returned to its original storage areas. By getting rid of unused items from the workstation, more vacant space was created and the items that were being utilized regularly could be found much faster.

The second step was Straighten, where items that was left after Sort were arranged and kept at the right places. Items that were most frequently used were kept close to the personnel's reach within the normal work area. Consideration should be to reduce the frequency of bending, stretching and excessive movement (Konz and Johnson, 2000).

Once the garbage was removed and useful items organized, the third step was to ensure the workplace was clean and neat all the time. The Operators occupying the space would be responsible for there own work area cleanliness and not relying on the janitors' routine cleaning.

After the effort had been made to tidy up and organize the work area, the next step was to instill discipline to ensure all effort would not slip by. This was where Standardize came into the picture to put a standard routine in place to maintain 5S practices. Implementing random and strict audits should be used to maintain the standards. Often, companies had 5S award as a token of appreciation for the department that performed best on the 5S activities for a particular predefined timeframe to congratulate the best 5S performers and to motivate others to achieve a high 5S standards.

Once a 5S culture and system was put into place, the focus of 5S would shift to a higher level where improvement opportunities were constantly being explored to nail down the trend and root causes of 5S findings, so permanent fixes could be implemented to Sustain the operation. For example, if during routine 5S audit it was captured that a garbage chute always had rubbish falling outside the intended garbage bin, a larger bin or a better chute should be installed instead of keeping the spillage and perform clean up during 5S.
These records should be kept to identify the most common, dangerous, longest lasting issues. Once a considerable amount of cases were captured, a Pareto charts may be used to identify the most common or severe case so prompt attention could be given to rectify the issues.

A successful 5S implementation would depend greatly on the commitment from top management in upholding a good exemple by doing what they preach, and full support for all levels of the organization. This was emphasized in studies by Nwabueze (Nwabueze, 2001) and O'hEocha (,2000). Ho's research (Ho, 1997) had created a proprietary 5S audit worksheet to aid the implementation of 5S in workspaces.